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Theory and methodology of appliance standards

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Abstract

Interest in appliance energy efficiency standards is spreading from North America and Europe to many other countries around the world. This article discusses two basic methodologies for performing energy and economic analyses that are used to develop energy efficiency standards. Procedures for setting standards that are based upon those analyses are also discussed. Additionally, the future direction of appliance standards is briefly discussed.

Keywords: Appliance; Energy efficiency; Methodology; Standards

1. Introduction

In North America, the first comprehensive energy efficiency standards for appliances were established in the State of California, USA in 1977 [1]. These efficiency standards were followed by additional ones in several other states. Eventually, this heterogenous mix of standards in various states motivated appliance manufacturers to develop national consensus standards with efficiency advocates; these consensus standards were enacted into law as part of the 1987 US National Appliance Energy Conservation Act (NAECA) [2]. The US standards are discussed in detail in two other articles [3,4]. At the same time as the US was developing labels and standards, similar activities were taking place in European nations and elsewhere. The history of labels and standards activities in Europe, Japan, Australia and Canada are discussed in other articles in this issue [5–8]. Australia, Canada, China, the European Union, Korea, Japan, Mexico and the Philippines have all developed efficiency standards for selected appliances. International activities are also discussed in another article in this special issue [9]. In many countries, efficiency standards are increasingly seen as a significant component of a national policy for reducing both carbon dioxide emissions and power plant construction. For some products (e.g., air conditioners), peak power reductions are also possible.

This article describes the methodologies that have been developed to select efficiency levels and to analyze the energy, economic and environmental impacts of alternative efficiency standards. The two main approaches (statistical and engineering/economic) to carrying out analyses used to set standards will be discussed in detail. Additionally, we will discuss the overall process of turning these analyses into efficiency standards.

2. Approaches to developing standards

There are several elements to a well-thought out procedure for establishing appliance energy efficiency standards (see Fig. 1). For the purpose of this article, it is assumed that there already exists legal authority to establish standards. The first step that must be taken in developing standards is to establish a test procedure by which to measure energy consumption or energy efficiency of an appliance. Labeling of appliances (as to their energy use) is a useful step in educating consumers, but not absolutely necessary for establishing standards. Once test procedures are in place, efficiency standards can be established through statistical or engineering analyses (to be discussed later) or some other procedure (e.g., a consensus approach, as in Japan). Finally, monitoring and enforcement processes can be developed to ensure compliance with efficiency standards.

2.1. Test procedures

The key element in developing standards is the establishment of a test procedure for each product type (e.g., refrigerators, clothes washers) of interest. The test procedure (or protocol as it is sometimes called) provides a method by which the efficiency or energy use of a product can be measured. Some test procedures also provide methods to measure

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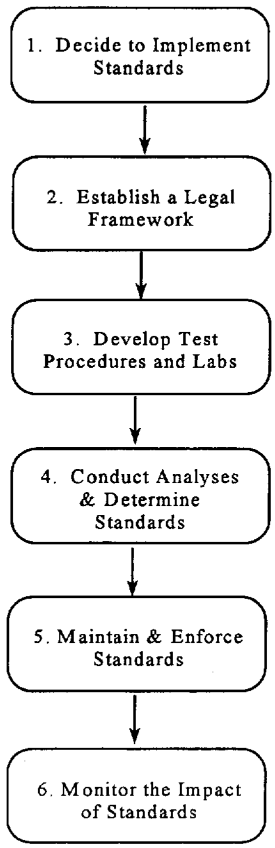

Fig. 1. The steps are shown for implementing appliance and lighting energy efficiency standards.

performance aspects of an appliance, for example clothes washer washing ability or refrigerator food freezing capacity. Test procedures have at least two goals: correctly ranking models by efficiency and providing reasonably accurate estimates of actual in home energy use. Presently, test procedures often differ from country to country. The European Union (EU) mostly uses international test procedures established by the ISO (International Standards Organization) and the IEC (International Electrotechnical Commission). However, the EU sometimes modifies these international test procedures and has their own numbering system, distinct from the ISO or IEC. The United States has its own set of test procedures that have been developed by the Department of Energy (DOE). The Canadian and Mexican test procedures are very similar to, but not always exactly the same as, those used in the US. Other countries sometimes use the ISO or IEC test procedures or their own unique test procedures

As an example of the diversity of test procedures, we are taking refrigerators and freezers. The European Community generally uses the ISO (International Standards Organization) test procedures as the basis for its own test procedures for refrigerators and freezers [10]. Tests are done at one of several possible ambient temperatures (depending upon what climate the refrigerator or freezer is rated for), for freezer loading, and without door openings. The freezer temperature depends on the rating (number of stars, from one to four) of the particular refrigerator/freezer. The Japanese have their own test procedure (although they are in the process of changing to the ISO) which is quite different than those of other nations. In the Japanese test, measurements are taken at two ambient temperatures with a schedule of door openings. The United States test procedure is significantly different from both of these test procedures. The US test is at one ambient temperature (different from either of the other two), with different cabinet temperatures, and without door openings. Additionally, the US test does not include performance aspects, as does the ISO test. Because of these notable differences in test procedures for the same product, direct comparison of energy use of refrigerators and freezers tested in different countries under different test procedures is not possible. These differences can also impede trade among countries.

In contrast to refrigerators, for microwave ovens, the standard established by the International Electrotechnical Commission (IEC) is widely used around the world. For wet appliances (dishwashers, clothes washers and dryers), the North American test protocols differ from the European (IEC) protocols and from the Australian/New Zealand protocols. For room air conditioners, the ISO test protocol 5151 has three possible rating conditions to choose from, one of which is the same as used in North America, Japan and Korea [11]. Test procedures are discussed in more detail in a paper by Meier and Hill [12].

2.2. *Types of efficiency standards*

Most of the North American appliance efficiency standards are in the form of minimum energy performance standards (MEPS), they establish minimum efficiencies (or maximum energy consumption) that manufacturers must achieve in all new products manufactured after a certain date. In the US, manufacturers have been given three to five years lead time (after publication of a standard) to make changes to their production facilities that may be required to achieve the MEPS. Standards can also be prescriptive in nature, when they require a particular feature or device to be installed in all new products. For example, beginning in January, 1987, all new gas-fired clothes dryers in the US had to eliminate standing pilot lights. Standards can also be based on average efficiency of a manufactured product. Such an approach has been used in Japan for lighting products where a sales weighted average efficiency must be satisfied by each manufacturer.

The US and Canada have chosen to establish mandatory standards with enforcement procedures. If the minimum energy performance standards are not met by manufacturers by the effective date, then they can be assessed with a monetary penalty for each unit shipped that does not meet the MEPS. As of the writing of this article, the authors do not know of any penalties applied to appliance manufacturers. Canada has a program established to periodically test a segment of the appliance market to determine if MEPS are being met. The US does not have such a testing program, but relies instead upon a self-policing mechanism carried out by the manufacturers themselves. Appliance manufacturers tend to check the products of their competitors and can notify the DOE when their measurements show a discrepancy with those reported by the manufacturer of the particular model in question. Some trade organizations also periodically run certification programs that check the efficiencies of products for which they report data submitted by manufacturers. These data are usually reported in directories available to the general public.

Some countries (e.g., Japan, Korea, Germany and Switzerland) have instituted voluntary or target levels rather than mandatory efficiency standards. These voluntary agreements are usually worked out in a consensus arrangement with the government and manufacturers taking part. They can be based on a statistical approach without wide spread public involvement. In some cases, (e.g., Switzerland), manufacturers are given a set time period to reach the voluntary standard and if they do not comply, the regulatory agency can substitute mandatory standards.

The methodologies described here have worked well for most standards setting exercises thus far. An exception has been where a leap in technology is required to reach the proposed efficiency level. An example of this case is electric storage water heaters for which there are no conventional technologies available to improve their efficiency much beyond that of existing models. The US DOE proposed a MEPS for this product that required use of a new technology, a heat pump water heater [13]. Two of the problems that have been raised with this proposal are that there are very few of these type of water heaters being manufactured and their first cost is very high relative to electric storage type water heaters with electric resistance heating. The first problem raises the concern that a mature market with high quality, reliable products might not exist by the date (1999) the standards would have taken effect and that the necessary infrastructure of trained installers and service technicians might not be in place in time. The second problem is that some consumers in some parts of the country (with lower electricity prices, colder ambient temperatures and lower water use), might not recover the increased purchase price of this more expensive product in reduced operating costs. This is known as an equity issue and is a concern common to standards setting for all products. It is a more extreme problem for cases of high incremental first cost and for climate sensitive products. One way to get around these problems would be to institute CAFE (corporate average fuel economy) type standards as has been done for automobiles and for some appliance standards in Japan. Such standards would require an average efficiency to be achieved by a set date, all models would not have to meet the same MEPS. This approach can solve both of the above problems by increasing the lead time for the water heater industry to convert to a significant amount of heat pump water heater production and would not require all consumers to employ that technology. Such an approach however, would require significantly more record keeping and a method to induce consumers to purchase enough of the higher priced product to meet the sales weighted average efficiency goal.

2.3. Technical/economic analyses

There are two widely-used approaches to setting energy efficiency standards, these are statistical or engineering/economic in nature. Both of these approaches are discussed in detail in this paper. In addition to these two methods, there are other arrangements (e.g., in Japan) where a less formal process is used to establish standards [6] by a group of industry and government participants using limited analyses but expert knowledge of the marketplace and of available technologies for a particular product.

A number of choices needs to be made before initiating the statistical or engineering approach. Depending upon the product of interest, there are usually reasons to separate it into several categories, sometimes known as product classes, based on consumer amenity. For example, for refrigerators and freezers, in the US there are product classes for manual defrost refrigerators and auto-defrost refrigerators and for side-by-side refrigerator/freezers and top-mount refrigerator/freezers. The reason for separate product classes is to allow for differences in energy consumption due to additional features or utility, for example manual versus automatic defrost of the freezer or configuration of the freezer and fresh food compartments (side-by-side or freezer on top of fresh food section). In the European Union, there are separate product classes for refrigerator freezers with different abilities to reach specific freezer temperatures. If there was only one product class for all refrigerator/freezers, those models with more energy intensive features (that provide a consumer utility) would have greater difficulty achieving an efficiency standard than those models without those same features. Another issue is whether to develop efficiency standards that are dependent upon the capacity or volume of the product. In all countries with refrigerator and freezer standards, the standards are a linear function of adjusted [1] volume. If maximum allowable energy consumption were not a function of adjusted volume (but instead a constant for all capacities), then larger-sized models would have a harder time meeting that standard. That would serve to discourage manufacturers from producing larger models. If the consumer utility of larger volume is acknowledged, then the standard should be a function of volume.

There are many ways by which a particular product can be disaggregated into product classes and this disaggregation can be both contentious and very important to the resulting energy savings from efficiency standards. For example, when electric storage water heaters were analyzed in the US, there was a debate about whether heat pump water heaters (HPWHs) should be considered as a design to improve the

[1] Adjusted volume depends upon the fresh food and freezer compartment volumes and temperatures.

efficiency of electric water heaters or if a special product class should be established for them. Some arguments in favor of a separate product class were that HPWHs were very different than standard electric water heaters in that sufficient air circulation is needed and there must be provision for condensate drainage. The US DOE decided that a separate product class was not needed because HPWHs provide the same utility as electric resistance storage water heaters and that all of the issues brought up were economic in nature and treated as such in the analyses [14].

2.4. Statistical approach

The statistical approach requires (i) data that may be easier to obtain and (ii) less analysis than the engineering/economic approach. The data required are those that give a current characterization of the marketplace for the products of interest, namely the number of models by efficiency rating currently available for sale. The impact of possible efficiency standards is analyzed as to the number of models remaining and number of manufacturers producing them. A standard level can then be selected after a decision is made as to the desired energy savings or the number of models that it is acceptable to eliminate. A significant advantage of the statistical approach is that the costs of achieving those energy savings are not explicitly determined. It is often very difficult to collect cost data from appliance manufacturers or suppliers to those manufacturers. The statistical approach has been utilized in the European Union (EU) and in Australia. A detailed statistical and engineering study of domestic refrigerators for the European Union was performed by the GEA (Group for Energy Efficiency), comprised of the Danish Energy Agency, NOVEM (the Netherlands Energy Agency) and ADEME (the French Environmental and Energy Agency) [15]. Similar statistical analyses have also been performed in Australia [16].

As an example of the statistical method, we discuss the analysis performed by the GEA for three star refrigerator/freezers [15]. Fig. 2 shows a set of energy use data for such refrigerator/freezers, for models available in EU countries in 1992. For each model, energy use is plotted as a function of adjusted volume. For this product class, and for the European test procedure (EN 153), AV is equal to the fresh food volume plus 2.15 times the freezer volume (volumes are in liters). Four lines are shown in this figure; they represent the average energy use (as of 1992) obtained through a regression analysis of all of the data points (called the reference line), a 10% energy savings line, a 15% energy savings line, and a long term standard line. The method used to obtain the first three of these energy savings equations is now described. The fourth line was obtained through an engineering/economic approach, and will be described later.

After calculation of the regression line, the least energy efficient model is found and replaced with a model of higher efficiency. The number of models stays constant. The energy savings for the replaced model is calculated and energy savings are aggregated until the total reaches the goal (10%, 15%, or whatever). The minimum efficiency line is defined as the line of maximum efficiency index. The efficiency index of a model is the percentage that the energy use is above or below the reference line. There are many ways to replace the least efficient models with more efficient ones. The GEA studied four ways of replacing the least efficient models. These are to replace it with: (i) a fictitious unit of similar adjusted volume but having the closest energy efficiency index; (ii) an existing unit with the closest adjusted volume and energy efficiency index; (iii) a fictitious unit with an adjusted volume and an energy efficiency index calculated as

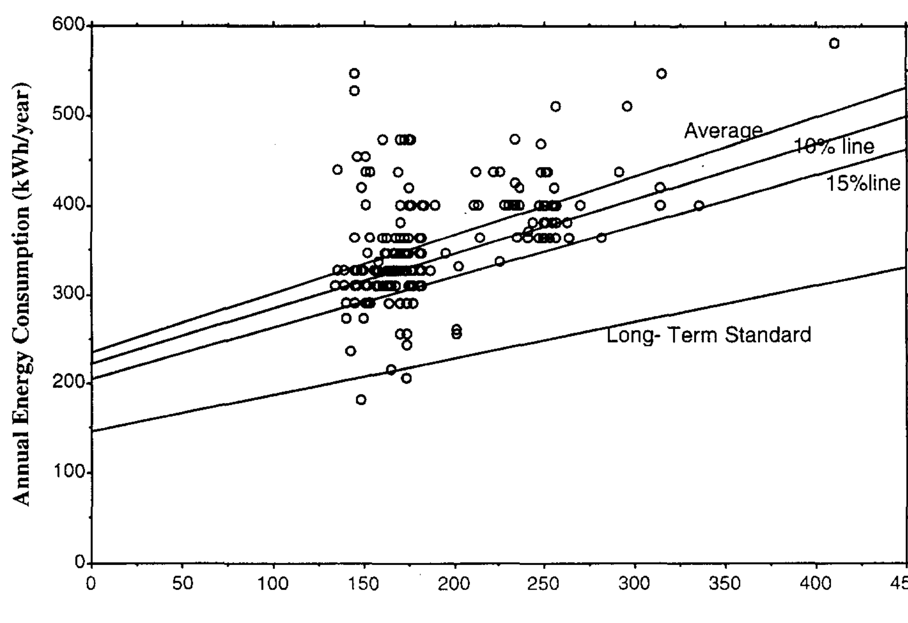

Fig. 2. Annual energy use of three star EU refrigerator/freezers is shown as a function of adjusted volume. Potential standards equations are also shown.

averages of the other units within the same volume interval; (iv) a fictitious unit of similar adjusted volume and energy efficiency index which is the average of the other units within the same volume interval. The volume interval is arbitrary, but should not be too large. The analyses performed by the GEA utilized method (iv). The report stated that it (method (iv)) is thought to represent the behavior of the appliance industry in the replacement process of inefficient appliances by improved units. Alternative approaches are still being considered in an analysis of clothes washers.

2.5. *Engineering/economic analysis*

The second approach to standards setting by engineering/economic, analysis seeks to determine the costs of efficiency improvements and the impact on consumers through economic analyses, including life-cycle cost and payback period calculations. It could also include impacts on national or regional energy use, manufacturer impact, electric or gas utility impacts and environmental impacts. In contrast to the statistical approach, one significant advantage of the engineering/economic approach is that it allows for consideration of new designs that are not already included in existing models or of some combination of designs that result in higher efficiency than is found in any existing models. A potential disadvantage is that the efficiency and cost of a projected model may be subject to significant uncertainty because it has not been mass produced. Projecting prices (from estimated manufacturer costs) of models that are more efficient than any existing models on the market is difficult and subject to many unknowns such as uncertainty and variation (over time and for models with differing efficiencies) in markups used by distributors and retailers of appliances and differences between the way appliance manufacturers (who do not have to follow the approach shown in the engineering analyses) and the theoretical technical analyses arrive at efficiency improvements.

2.5.1. *Engineering*

There are several parts to an engineering/economic standards analysis; this approach has been widely used by the Lawrence Berkeley National Laboratory (LBNL) for the US Department of Energy (DOE). It has also been used to propose long-term refrigerator efficiency standards in the EU [15]. First, an engineering analysis is carried out for each product class within a product type; it produces manufacturing costs for improving the efficiency of a baseline model. Installation and maintenance costs are also calculated during the engineering analysis, summarized in Table 1.

The first step in the engineering analysis is the segregation of product types into separate classes to which different energy-efficiency standards apply. Classes are differentiated by the type of energy used (oil, natural gas, or electricity) and capacity or performance based features that provide utility to the consumer and affect efficiency. The discussion above on the technical/economic analysis provides more information on this first step.

Table 1
Steps for Engineering Analysis

1.	Select appliance classes
2.	Select baseline units
3.	Select design options for each class
4.	Calculate efficiency improvement from each design option
5.	Combine design options and calculate efficiency improvements
6.	Develop cost estimates (include installation and maintenance) for each design option
7.	Generate cost-efficiency curves

A baseline unit is the starting point for analyzing design options for improving energy efficiency. The characteristics of the baseline model should be representative of its class. For products that already have standards, a baseline model with energy use equal to the minimum efficiency requirement is usually chosen. For products without an existing standard, a baseline model can be chosen that has an efficiency equal to the minimum or the average of the existing distribution of models. Selecting the least efficient model as the baseline is recommended since this permits analysis of trial standards at all possible levels of efficiency starting from eliminating the least efficient models.

Design options represent changes in the design of a baseline model that improve its efficiency. These options are considered separately and also in combinations when appropriate. For each design option or combination of design options, energy use or efficiency is determined through measurements or through calculations using the appropriate test procedure. These calculations are usually performed with simulation models or with simpler spreadsheet models that account for the various energy using components of a product.

The expected costs of manufacturing, installing and maintaining each additional design option must be calculated. Data are usually obtained from appliance manufacturers and component suppliers (e.g., compressor and fan motor manufacturers). The cost and efficiency data are combined and displayed in tabular or graphic form. In some cases, manufacturer costs are very difficult to obtain and it may be necessary to go directly to retail costs; this is a feasible approach if all the designs under consideration are already found in the marketplace. This approach was used in an analysis of fluorescent lamp ballasts [17]. Obtaining average retail prices of particular designs can also be very difficult because of the significant temporal and regional variations in consumer prices. It is also very difficult to find two models of a product that are only different in the presence or absence of a particular design feature.

Fig. 3 illustrates the results of an engineering analysis for a typical 18.2 ft^3 (515 l) top-mount auto-defrost refrigerator/freezer that used a simulation analysis. In large part, this analysis was used as the basis for the consensus efficiency standards proposed by the US DOE for July, 2001 [18]. Manufacturer cost is plotted as a function of refrigerator

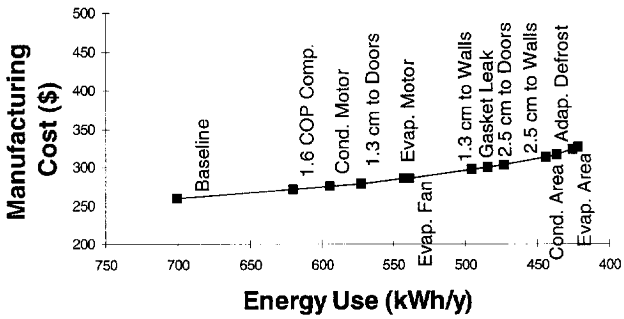

Fig. 3. Manufacturer cost as a function of energy use is shown for a typical US top-mount auto-defrost refrigerator/freezer.

annual energy use. Efficiency gains become more expensive as the energy use decreases. Most of the design options are self-explanatory. The compressor efficiency increases from a COP of 1.37 to 1.60 (or an EER of 4.7 to 5.45). Door insulation thickness is first increased from 3.8 to 5.1 cm. (1.5 to 2.0 in) and then from 5.1 to 6.3 cm (2.0 to 2.5 inches). Insulation in the sides of the cabinet is also increased by similar amounts. The evaporator and condenser fan motors are improved in efficiency so that their power consumptions decrease from 9.1 and 12.0 W, respectively, to 4.5 W each. Other design options shown are reduced gasket heat leak, adaptive defrost and increased heat exchanger area. The use of vacuum panel insulation was also studied although it is not shown here.

The proposed 1998 refrigerator standards could not be arrived at through a statistical analysis where the standard level is typically located somewhere within the distribution of existing models. The proposed maximum energy use standard for an 18 ft^3 top-mount auto-defrost refrigerator/freezer was at an energy use below 500 kWh/y, and at the time of the analysis there were no models at such a low energy use. For the refrigerator efficiency standards proposed for 1998, a hybrid approach has been utilized; the US DOE has provided engineering and economic analyses to all participants in a refrigerator standards negotiating group and these analyses have been utilized as a basis for discussion. A detailed discussion of this hybrid approach can be found in another paper [19]. Participants in this group included manufacturer representatives, efficiency advocates, representatives from electric utility companies and representatives from State energy offices.

2.5.2. Life cycle cost analysis

Once the engineering analysis is completed, it is customary to analyze the economic impact of the potential efficiency improvements on consumers by carrying out a consumer life cycle cost analysis. Consumer prices are generated, by applying markups (multipliers that convert manufacturer costs to retail prices) to the manufacturer costs or by directly determining retail prices from a survey. This survey approach works only if the designs being assessed are present in products that are currently manufactured. Surveys of retail price are also limited because variability in retail price due to different features and among brands, regions and retailers obscures the underlying relationship between efficiency and manufacturer cost. Additionally, it is often difficult to find two models of a product which differ only in the presence or absence of the particular option being evaluated.

The life cycle cost (LCC) is the sum of the purchase price (PC) and the annual operating expense (OC) discounted over the lifetime (N, in years) of the appliance.

$$LCC = PC + \sum_{1}^{N} \frac{OC_t}{(l+r)^t}$$

If operating expenses are constant over time, the above equation reduces to

$$LCC = PC + (PWF)(OC)$$

where the present worth factor (PWF) equals:

$$PWF = \sum_{1}^{N} \frac{1}{(l+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(l+r)^N}\right]$$

The LCC is calculated in the year standards are imposed, using a discount rate r to determine the present value of future energy cost savings. Installation and maintenance costs are also included in the LCC analysis. Installation costs are added directly to the purchase cost and maintenance costs are added to the operating cost and discounted along with the energy cost. For water using appliances, such as clothes washers, the cost of water and detergent should also be considered. In the US, there has been much debate over the proper choice of a discount rate. In response to the comments from efficiency advocates and manufacturers, the DOE has calculated LCC for a range of discount rates.

Fig. 4 shows the LCC analysis results at three discount rates (2, 6 and 15% real) for a top-mount auto-defrost refrigerator/freezer. These curves were used by the participants in the process of setting the proposed 1998 refrigerator/freezer consensus standards. At a 6% discount rate, the LCC minimum (where the consumer receives the most benefit) occurs around 450 kWh/y. At the lower discount rate, the LCC minimum shifts towards lower energy consumption options while at higher discount rates, the LCC minimum is seen to shift towards higher energy consumption options. Options below 470 kWh/y were rejected for use in a proposed stan-

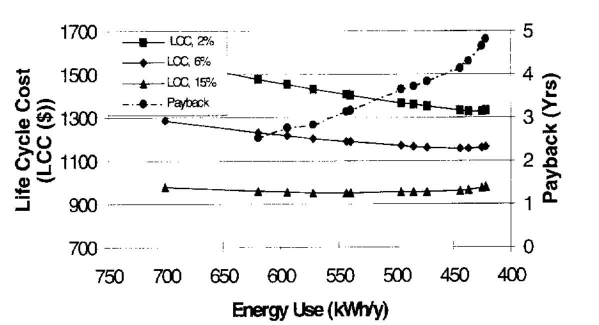

Fig. 4. Cumulative payback period and life cycle cost (for three discount rates 2, 6 and 15%) are shown as a function of energy use for a typical US top-mount auto-defrost refrigerator/freezer.

dard because the parties to the negotiation and DOE agreed that adding 2.54 cm of insulation thickness to all sides of the refrigerator would adversely impact the ability of such refrigerators to fit into fixed spaces in existing kitchens. It was assumed that internal volume remains constant as insulation thickness increases. If the goal were to maximize energy savings, then a policy maker could choose a standard that is beyond the *LCC* minimum as long as there is still a reduction in *LCC* relative to the baseline.

2.5.3. Payback period analysis

The payback period measures the amount of time needed to recover the additional consumer investment (*PC*) in increased efficiency through lower operating costs. Payback period (*PAY*) is found by solving the equation:

$$\Delta PC+\sum_{1}^{PAY}\Delta OC_t=0$$

for *PAY*. In general *PAY* is found by interpolating between the two years when the above expression changes sign. If the operating cost (*OC*) is constant, the equation has the simple solution:

$$PAY=-\frac{\Delta PC}{\Delta OC}$$

The payback period is the ratio of the increase in purchase price and installation cost (from the base case to the standards case) to the decrease in annual operating expenses (including maintenance). A payback period greater than the lifetime of the product means that the increased purchase price is not recovered in reduced operating expenses. Payback periods can be computed in two ways, first from the engineering analysis where cumulative payback for each design option level relative to the baseline is calculated and second by using a distribution of design options projected for the base case without standards. The second method tends to yield payback periods that are a little longer than the first method. In the second payback calculation (which is used to evaluate potential standard levels), only those designs that are eliminated by the standard level are included in the calculation of paybacks. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard level under consideration.

Fig. 3 shows the payback periods obtained by the second of the two methods described above. The right-hand axis shows the cumulative simple payback period and uses the estimated base case distribution of model efficiencies when calculating paybacks for the various design options. The consumer payback period at the reduced gasket heat leak design option, which has an energy use close to the consensus standard is less than four 4 years. Incremental payback periods can also be calculated to determine the marginal benefit of adding the last design option to the previous design level. That approach is not used in the US standards setting process.

The last step in establishing efficiency standards for this product class was to determine how energy use varies with adjusted volume. One way of doing this is by performing simulation analyses for several top-mount models with different adjusted volumes but otherwise similar characteristics. These analyses would be performed for each design option level leading to a regression equation for each level. Once the energy savings level was decided, a linear equation for energy use as a function of adjusted volume could be chosen. Details of this method can be found in another paper [20].

2.5.4. National energy savings

Policy makers are often interested in knowing the national or regional (e.g., for the EU) energy savings from proposed energy efficiency standards. These energy savings estimates can be converted into reduced emissions of carbon dioxide and other combustion products. Also of interest are peak load reductions, reduced oil imports and avoided power plant construction. The expected national energy savings from alternative standards are calculated by using forecasting models or simpler spreadsheet models that estimate annual energy use under different scenarios. In the US, for the residential sector the LBL-REM model is used and for the commercial sector the COMMEND model is used. These are described below. In most other countries, a spreadsheet model is used to estimate energy savings.

2.6. Lawrence Berkeley National Laboratory Residential Energy Model (LBL-REM)

The LBL-REM [21] is an end-use forecasting computer program under continuous development since 1979. This model simulates appliance purchase choices made in households, usage behavior and subsequent energy consumption.

Input data include engineering characteristics of appliances and buildings, economics (energy prices, household income, prices, installation and maintenance costs of appliances and equipment, and models of fuel and technology choice), and demographics (number of existing and new households by type and appliance holdings. The model simulates five types of activities: technology and/or fuel choice during appliance purchases; building shell thermal integrity choice for new homes and during retrofits; appliance efficiency choice; usage behavior; and turnover of buildings and appliances. The basic accounting equation for annual energy consumption by fuel by building type involves the product of five terms: number of households; percent of households owning the appliance of interest; unit energy consumption; usage behavior adjustment; and influence of the thermal shell. (The last two factors apply primarily to space heating and cooling.)

Output includes national (US) energy use by end use and building type (single family, multifamily, and mobile home), by fuel type, by year (1980–2030). Economic outputs include annual expenditures by households in purchasing appliances, and in energy expenditures. Differences between a base case and a policy case provide a measure of the net impacts of the policy. Estimation of a base case (no standards case) is difficult and important to the calculation of energy savings. The base case must take into account the impact on sales of more efficient products from any voluntary or utility programs such as labels, DSM or other market conditioning approaches. Summing discounted energy cost savings and subtracting additional first costs over a time period provides a net present value for the policy.

2.7. *Commercial Energy End-Use Model (COMMEND)*

COMMEND [22] forecasts energy use by end use and building type. COMMEND models thirteen building types, ten end uses, and three fuel types. Forecast fuel prices and floor space are exogenous inputs to COMMEND. COMMEND models selection of equipment usually based on life-cycle–cost criteria. There are four groups of decision makers, each with a different discount rate. Short-run price elasticities for utilization of energy services are included. Interactions between lighting and space-conditioning energy use are also handled within the model. COMMEND has been used in the US to analyze alternative efficiency standards for fluorescent lamp ballasts.

The basic relation modeled by COMMEND for the ballast analysis is that lighting energy use is the product of floor area (ft^2 for a given end use), design footcandle level (lm/ft^2), shares of delivered lumens by each system, and operating hours, divided by system-specific constants of system efficacies (lm/W), fixture efficiency, and room factors. Such energy consumption calculations are summarized first over lighting systems, and then over building types to generate the total sectoral lighting consumption.

The analysis integrated a variety of data: current market shares; forecasted future market shares; recent usage trends for various lighting products; and the LBNL engineering analysis of wattages, costs, system efficacies, fixture efficiencies, and room factors. The results of this integration were used first to develop a base case of interior lighting consumption. For the alternative energy efficiency levels, ballasts that are less efficient were eliminated one step at a time. The difference in forecasts between the base case and the efficiency level is the net energy impact.

2.7.1. *Manufacturer impact analysis*

In the US, analyses have been performed to determine the impact of potential efficiency standards on appliance manufacturers. Thus far, such analyses have not been performed in any formal way in other countries. Outside the US, manufacturer impacts are usually discussed in an informal consensus type approach. In the US, these analyses have been very controversial and criticized by some in the appliance manufacturing industry as not realistic in representing their situations. After the engineering analysis has been completed and the appropriate classes, design options, baseline units, and cost-efficiency curves have been developed, the manufacturer impact analysis evaluates the impact of increased capital and variable costs on manufacturer profitability.

The manufacturer impact analysis makes use of a computer model known as the Lawrence Berkeley National Laboratory-Manufacturer Analysis Model (LBL-MAM) [23]. The LBL-MAM collects into one spreadsheet all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation. Generally, a change in standards affects the manufacturer in three distinct ways. Standards require additional investment, they change production costs, and affect revenue.

The additional investment due to standards tends to take three major forms. The most obvious form of investment is the purchase of new equipment and possible updating of plants. This cost is first evaluated from engineering data and then amortized by taking into account the life of the investment, the timing of the expenditures, tax laws, and the cost of funds. An additional (and sometimes larger) investment is made as old inventory is replaced with more expensive new units. The model assumes that previous inventory ratios (ratio of inventory to sales) are maintained. A third form of investment tracked by LBL-MAM is the change in the transactions demand for cash that accompanies a change in revenues.

The second effect of a change in standards is a change in production costs. Any changes in the costs of production are modeled by coupling changes in unit costs with changes in product shipments.

Finally, revenue is affected both by price and shipments. Price is determined by computing the markup over long-run marginal costs, and then using the markup to determine an optimal price [2]. Shipments (demand) are determined by price elasticities and market discount rates, coupled with the standards-induced changes in price and operating costs.

The LBL-MAM computes three primary and several secondary measures of impact. The three primary measures, return on equity (ROE), industry net present value, and net income are presented because they can each move in opposite directions. Return on equity is defined as the common financial ratio of net income over shareholders' equity. Industry net present value is the discounted present value of the sum of the annual total value of the industry. Net income is the income to the firm after costs and taxes have been netted from revenues. For instance, if net income increases, but assets and thus equity increase by a greater percentage, ROE will decline. If the decline is large, the net effect will be viewed as negative, but if a small decrease in a healthy ROE is accompanied by a large increase in net income, the net effect might be viewed as positive. Other outputs of the model are total shipments, price, revenues, and average wholesale price.

[2] This follows from the standard economic assumption that firms seek to maximize economic profit, where economic profit is revenue minus economic cost, and economic cost includes the cost of equity and all taxes.

These variables help explain the origins of changes in the primary inputs.

2.8. Other analyses

Other impact analyses are sometimes carried out. For example, an electric utility impact analysis can be performed to describe the effects of standards on marginal costs of electricity, generating capacity growth, changes in regional capacity and energy demand, and changes in utility revenue and costs. An environmental impact analysis describes standards-induced changes in emissions of oxides of carbon, sulfur and nitrogen from combustion of fossil fuels for electricity generation and in homes.

3. Setting efficiency standards

Once a statistical or engineering/economic analysis is completed, a process is needed for selecting the standard levels for various products. There are many ways in which this can be done. For example, a regulatory, consensus, or hybrid approach may be used. The straight regulatory approach is typically a formal approach with opportunity for the public (sometimes called stakeholders) to provide oral and/or written comments. This approach has been used in the US and to some extent in Australia, Canada, and Mexico. In the EU, the approach is less formal in that public hearings are not held to solicit public input (although manufacturer input is sought through less public meetings). In the US, the first step in the DOE rulemaking process has been the publication of an Advance Notice of Proposed Rulemaking (ANOPR). The purpose of this notice is to inform all interested parties of the product types (and classes) for which DOE intends to consider energy efficiency standards. Additionally, the designs to be analyzed, and computer models to be utilized, are described. Information received by the DOE during the public comment period is considered in the preparation of the Notice of Proposed Rulemaking (NOPR). The NOPR presents the proposed policy, the results of the analysis and the alternatives considered. During another public comment period, hearings are held in Washington, DC. The oral and written comments received on the NOPR are considered in preparing a final rulemaking which contains any new energy efficiency standards.

In a consensus approach, two or more groups get together and decide on the standards through a joint process. These groups could be some combination of a government regulatory agency, environmental/consumer groups and appliance manufacturers. They may base their agreement on what is available in the current marketplace and proposals by the efficiency advocates or the manufacturers of the product of interest. This approach was used in the United States in establishing the first national efficiency standards that were incorporated into law in 1987. The consensus approach was also used to some extent in finalizing the Australian efficiency standards for refrigerators and water heaters and for some Japanese standards.

In a hybrid approach, the technical analyses are provided to the parties that are attempting to reach a consensus on efficiency standards. A series of meetings are usually held allowing for review and comments on the analyses by all interested parties. The analysts modify their analyses based on comments received from the stakeholders. This approach was used in the US from 1992–94 in the refrigerator/freezer rulemaking proposed for 1998 [18]. The hybrid approach has the advantage of providing a process whereby stakeholders are involved early, more complete and accurate data are provided, and analyses can be modified before a proposed rule is issued. A disadvantage with the hybrid approach is that it takes longer to complete the NOPR; however, the time between the proposed rule and the final rule should be shorter.

3.1. Improvements in standards setting process

Now that several countries have gone through the process of establishing efficiency standards, in some regions there has been a demand by appliance manufacturers for a greater input into the process. Recently, the US Department of Energy ended a critical review of the standards process, and made changes in the approach [24]. They elaborated on the procedures, interpretations and policies that will guide the DOE in establishing new or revised energy efficiency standards. The process provides for greatly enhanced opportunities for public input, improved analytical approaches, and encouragement of consensus-based standards. One of the objectives of the new process is to reduce the time and cost of developing standards, at the same time the new approach requires that earlier and more interaction occur with stakeholders and that additional analyses are performed (e.g., sensitivity of economic impacts on population subgroups and additional uncertainty analyses).

4. Conclusions

There is no single methodology for establishing a standard. The best approach may differ with goals, appliance type and the local conditions. Most approaches begin with a data collection phase, followed by an analysis phase and then a standards setting process. In general, the different appliance standards setting methodologies have been successful in achieving their objectives, new or revised efficiency standards. They have been used to generate prospective data on the impact of efficiency standards on consumers, manufacturers, utilities and the environment. These data have served to focus discussions of possibilities, and to quantify the implications of uncertain assumptions. In most cases, decision makers have used these data to implement effective policies.

The analysis methodologies and the standard setting processes can be improved. In the US, several changes are already occurring in the efficiency standards arena, including increased participation of manufacturers in the process. In the international arena, there has been a meeting to discuss the harmonization of test procedures and appliance efficiency standards and there will likely be other follow up meetings [25]. It is possible that some enhancements in the present methodologies will be needed to assess standards across countries or regions. One such methodology, emphasizing uncertainty analysis, has been described previously [26]. This approach allows various parameters that influence economic determinants to be assessed as to their importance, thus the robustness of one set of standards can be analyzed across countries with different values for the important input parameters (e.g., fuel price).

As a result of the critical review of the standards process in the US, it is expected that, in the future, more attention will be focused on market transformation during the standards setting process. Much of the analyses described here can be used to assist sound decision making about appropriate government programs. Cost-benefit analyses from multiple perspectives (consumer, manufacturer, utility) and national energy/environmental impacts should still be assessed when comparing various potential market transformation programs.

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